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Design and Analysis of A Multi Band Electrically Small Antenna Using Ceramic Material Substrate

***Abstract**. A Multi band modified S shaped electrically small microstrip patch antenna on Aluminium tri-oxide ceramic substrate is designed and analyzed in this paper. The proposed microstrip line fed miniature patch antenna designed by using high frequency electromagnetic solver and the computed results are analyzed by using finite element method. It is observed from obtained results that, the achieved -10 dB return loss bandwidth 410 MHz in Ku band and 350 MHz in K band, 1.5dBi average gain in total operating band, 97.3% of average efficiency are achieved for Ku and K applications. Furthermore, the co-cross polarization of radiation pattern and the current distribution along surface the radiating patch of the proposed antenna are analyzed.*

***Streszczenie.** W artykule przedstawiono projekt wielopasmowej prostokątnej anteny mikropaskowej o elektrycznie małych rozmiarach na podłożu ceramicznym z trójtlenku aluminium. W pracy wykorzystano pakiet programowy do obliczania pól elektromagnetycznych wysokich częstotliwości, a otrzymane wyniki poddano analizie metodą elementów skończonych. (**Projektowanie i analiza wielopasmowej anteny na podłożu ceramicznych o elektrycznie małych rozmiarach**)*

Keywords: Multiband antenna, Aluminium oxide, finite element method, ceramic material.
Słowa kluczowe: antenna wielopasmowa, tlenek aluminium, metoda elementów skończonych, materiał ceramiczny

Introduction

Owing to the rapid growth of wireless communication technology, miniature antenna plays a significant role for small size multifunctional devices. In recent days, all communication devices need to be small in size, compact, lightweight, in short should be portable. Moreover, portable devices obligatory to operate multiple frequency band applications to use in different areas or countries. Due to the availability of unused bandwidth, many researchers are concentrating towards Ku/K band application oriented antenna design. Recently, demand of satellite based portable communication devices are increasing noticeably, especially vehicle tracking, portable satellite station, weather forecasting etc. A considerable number of patch antenna have been developed targeting better performance for multiple frequency band applications due to lower performance of wired antennas. A low profile, compact, Antenna size reduction with multiband operation capability is still interesting topic for communication engineering researchers. A considerable research effort is given to antenna miniaturization to integrate with small form factor multi frequency devices without compromising the overall performance. There are several techniques have extensively studied by many researchers, such as using reactive impedance substrate [1], artificial magnetic conductor [2], EBG substrate [3], Metamaterials [4], Multilayer dielectric substrates [5] etc. Use of ceramic material substrate is one of the effective techniques for antenna miniaturization. Due to higher dielectric constant of the ceramic material substrate, the overall size of antenna can be reduced significantly without compromising the overall performance [6]. Many antenna technology researchers have comprehensively examined the use of ceramic material substrate for miniature antenna design in their article. A miniature antenna was designed using thick truncated textured Ceramic Substrate with the dimension of 14x13.6 mm^2 at 1.88 GHz resonant frequency and obtained 3.5 MHz of bandwidth [7]. A 25x10x4 mm^3 multiband dielectric resonator antenna designed for multi-standard mobile handheld devices [8]. A miniaturized patch antenna designed with 25.4x25.4x6.35 mm^3 dimension using low-temperature co-fired-ceramic (LTCC) substrates [9]. However, in terms of antenna size reduction or bandwidth enhancement there are still needs to put more research effort for miniaturization with better performance to meet the ever increasing demand for multiband applications.

In this paper, an 8 x 10 mm^2 patch antenna is designed on 1.5 mm thick Alumunium tri-oxide (Al_2O_3) ceramic material substrate and achieved 760 MHz of 10-dB total bandwidth, 4.5dBi peak gain and 97.3% of average radiation efficiency. The proposed antenna is comparatively smaller in size, better gain and higher radiation efficiency achieved than the reported antennas which is compatible for Ku band and K band applications. In addition, co and cross polarization of radiation pattern are analyzed and demonstrated.

Antenna Design and Configuration

The proposed modified S-shaped small patch antenna is designed and analyzed by using computer aided commercially available 3D full-wave electromagnetic field simulator HFSS [6]. The profile of the proposed antenna shown in Fig. 1 is designed on an 1.5 mm thick Aluminium tri-oxide ceramic substrate whose relative permittivity is 9.8 and relative permeability is 1. Due to higher dielectric constant and zero tangent loss Al_2O_3 ceramic material is chosen as substrate. Compare to conventional less expensive widely used FR4 substrate, Al_2O_3 ceramic material substrate reduces the overall antenna size dramatically and performs much better in terms of bandwidth, gain and efficiency. For the projected antenna design, S shape is obtained by cutting slots from the rectangular copper patch. The dimension of the radiating antenna can be determined by using classic numerical model as following [6]:

(1) $$w = \frac{c}{2 f_o}\sqrt{\frac{\varepsilon_r + 1}{2}}$$

(2) $$l = \frac{c}{2 f_o \sqrt{\varepsilon_r}} - 2\Delta l$$

In the above, w represents the width and l is the length of the patch, f_o is the center target frequency, c is the speed of light in vacuum in equation (1 & 2). Using following mathematical equation (3) the effective dielectric constant ε_e can be determined [6]:

(3) $$\varepsilon_e = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\sqrt{(1 + \frac{10h}{W})}$$

where h is the thickness of the substrate and ε_r is the relative dielectric constant. Due to the fringing field around the periphery of the patch, the antenna electrically looks larger than its physical dimensions.

By cautiously adjusting the length, width and slots of the proposed antenna, two preferred resonant frequency at 17.38 GHz and 20.85 GHz in the entire operating frequency band from 17 GHz to 20.50 GHz. There are many types of feeding techniques complied by different antenna designers. In the proposed antenna 2mm long 1 mm wide microstrip line is used to feed and mounted on a finite 8 x 12 mm^2 ground plane . It is noted that the first resonance shift with the feeding position. The feeding position is carefully determined 5.5 mm from zero point along X axis with the lower resonant frequency 17.38 GHz. A 50-Ω SMA connector is used for RF signal input at the end of the microstrip feed line. The cutting slot of the radiating patch has an effect the second last resonance. The detailed design parameters of the proposed antenna are tabulated in Table 1.

Table 1. Optimized design parameters of the proposed antenna.

Parameters	L_1	W_1	L_2	W_2	L_3	W_3
Value(mm)	10	8	1	.5	1	4.5
Parameters	L_4	W_4	W_5	W_6	h	
Value(mm)	2	1	5.5	1.5	1.5	

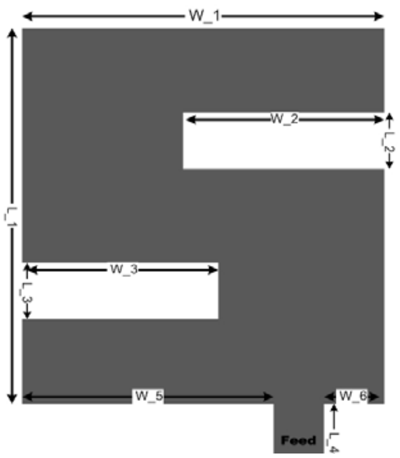

Fig.1. Geometry of the proposed antenna

Results and Analysis

The proposed multiband patch antenna designed and studied by using finite element method based high frequency electromagnetic simulator HFSS. The achieved results are plotted and analyzed by using computer aided tools. The performance of the proposed antenna involves return loss, gain, radiation efficiency VSWR and radiation pattern. Fig. 2 shows the achieved return loss of the proposed antenna. The achieved return loss (<-10dB) bandwidth are, 410 MHz from 17.16 GHz to 17.57 GHz, 180 MHz from 19.35 GHz to 19.53 GHz and 270 MHz from 19.73 GHz to 20.00 GHz. It can be easily seen that, 410 MHz and 450 MHz bandwidth obtained in Ku and K band consecutively. There are three resonance observed in the total operating frequency band, but in terms of gain and return loss the preferred resonant frequencies are 17.38 GHz for Ku band, 19.48 GHz and 19.85 GHz for K band. The gain of the proposed antenna in operating band is shown in Fig. 3. It can be clearly observed that the gain achieved in three resonances 3dBi, 0.35dBi and 0.5 dBi at 17.38 GHz, 19.48 GHz and 19.85 Ghz respectively. The peak gain 4.6 dBi reported at 17.20 GHz in whole operating frequency band. The overall gain of the proposed antenna can be increased by using thick substrate or larger radiating patch. Nonetheless, there is a tradeoff between substrate thickness, patch size and antenna gain. Fig. 4 illustrates the radiation efficiency of the proposed antenna and it is undoubtedly observed that the 97.8% efficiency achieved in the whole operating frequency band which is considered extraordinary efficient. Fig. 5 plots the voltage standing wave ratio (VSWR) with frequency of the proposed antenna. Generally, VSWR value less than 2 is acceptable in the operating band for microstrip patch antenna. It can be easily seen that, achieved VSWR value in the desired bandwidth of the operating frequencies are less than two.

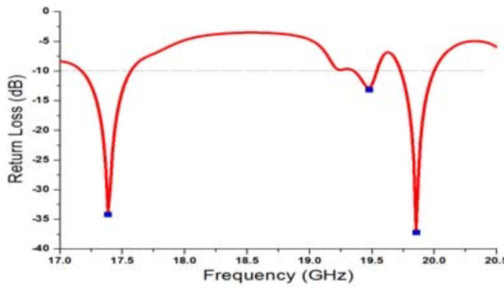

Fig. 2. Return loss vs. frequency of the proposed antenna.

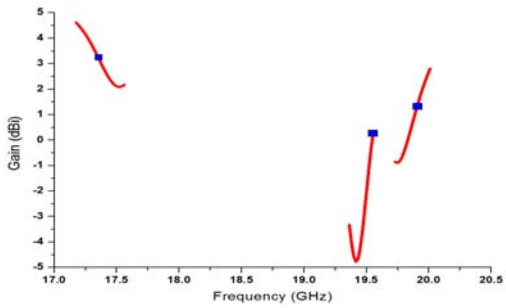

Fig. 3. The achieved gain vs. frequency of the proposed antenna

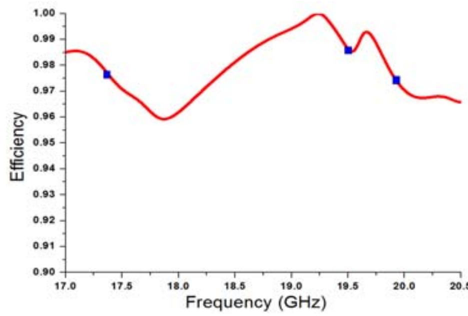

Fig. 4. Frequency vs. radiation efficiency of the antenna.

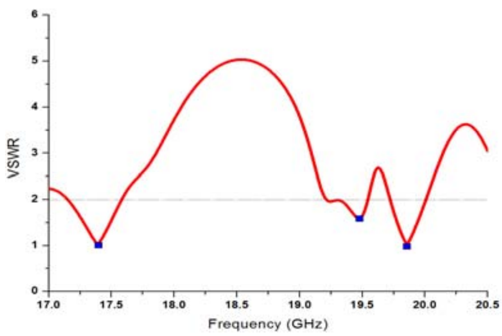

Fig. 5. Graph of VSWR vs. frequency of the antenna.

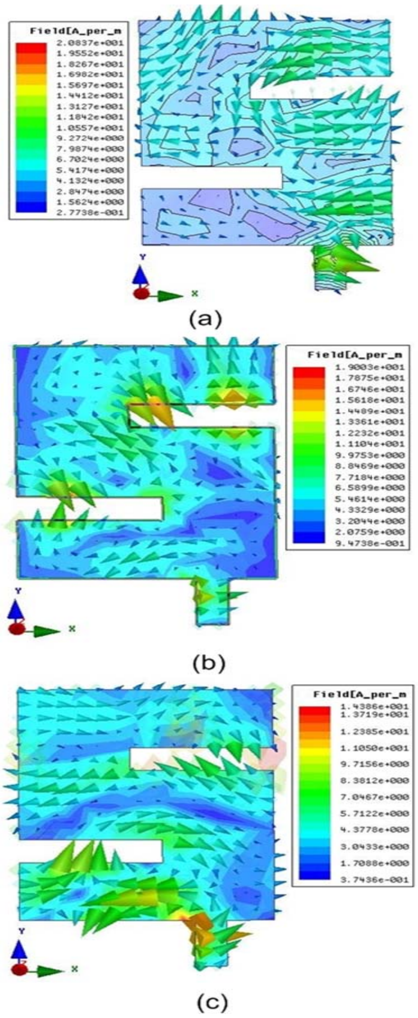

Fig. 6. Electric field distribution of proposed antenna at (a) 17.38 GHz, (b) 19.48 GHz and 19.85 GHz.

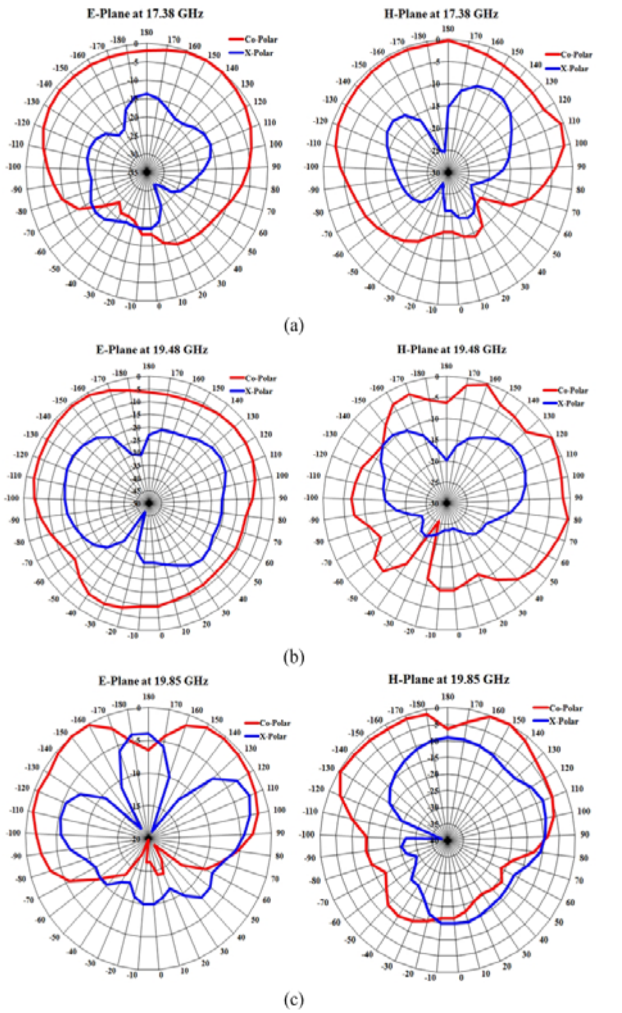

Fig. 7. E-H plane (a) 17.38 GHz, (b) 19.48 GHz and (c) 19.85 GHz radiation pattern of the proposed antenna.

Fig. 6 illustrates the surface plots of the electric field of the proposed antenna for (a) 17.38 GHz, (b) 19.48 GHz and (c) 19.85 GHz. Due to the large amount of electric field radiated from the feeding line it can be easily noticed that, near the feeding point and cutting edges concentration of the electric field is stronger. Furthermore, the electric field distribution at higher resonance is stronger than lower resonance. The far field E-H plane radiation pattern at (a) 17.38 GHz, (b) 19.48 GHz and (c) 19.85 GHz are illustrated in Fig. 7. The co and cross polarization can be clearly observed and it is noted that, the effect of cross polarization at higher resonance is more that the lower resonance. The results of proposed antenna parameters are compared with some existing antenna in Table 2. It can be clearly seen that reported antennas are either larger in size, lower gain or less efficient compare to proposed antenna.

Table 2. Comparison between proposed and existing multiband antenna.

	[10]	[11]	[12]	[13]	Proposed
Dimension (mm^2)	130x95	45.46x44.69	17.5x10	14.5x14.5	10x8
Bandwidth (MHz)	642	1400	1250	12,200	860
Avg. Gain (dBi)	2.006	N/A	2	0.7	2.9

Conclusion

A 10x8x1 mm^3 modified S shaped line fed electrically small patch antenna is proposed for Ku and K application. The proposed miniature antenna using Aluminium tri-oxide ceramic substrate appears to be a promising candidate to be integrated with small form factor multiband devices. It can be clearly seen from the results that, 410 MHz in Ku band and 450 MHz in K band 10dB bandwidth are achieved. Furthermore, 2.9 dBi average gain and 97.5 % radiation efficiency are obtained in the operating frequency band. The E-H plane radiation pattern and electric field distribution of three resonant frequencies are analyzed in this paper. Compare to recently available multiband patch antenna, the projected antenna is compact smaller in size with better performance in terms of bandwidth gain and efficiency.

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